The Research and Application of Descriptive Programming for Robot Control System

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Abstract

This paper develops a G-code programming tool for a SCARA robot with four degrees of freedom, which is easily operated by users. At first, in order to establish a connection between the G-codes which are entered by users and specified actions of the robot, a decoding protocol is formulated. Then, a communication protocol is planned for upper computer sending the decoding files to lower controller through a serial port to drive the robot.

The protocols are applied to decode modules and communication modules developed for recognizing the codes input in the form of G-code by users through interface. The real-time controlling of the robot's movement, like point-to-point motion, linear motion, circular motion and hold-up are realized respectively. The control system's performance is evaluated on a SCARA robot which is a robot platform with four degrees of freedom. The results show that the proposed protocols guarantee commercially applicable at pre-establishing performance by properly G-code programming. The effectiveness and convenience are verified by experiments.

Keywords

G-code; Decoding; Serial Port; Robot

Introduction

Industrial robot programming techniques are playing a more and more important role in the efficient application of the industrial Robot. Traditional online programming techniques including teaching programming and sensor aided programming are lack of flexibility and highly costly to implement，and the existing offline programming software usually needs to compile the system graphics format to create code for controlling Robot. So it is obviously time-consuming for user to learn about internal operational mechanism and do the programming work. G-code has been applied to various CNC machine tools widely, which is a generic and easily acceptable interpreted programming language to specify motion. Based on these considerations above, this paper designs a kind of G-code compiler, which aims to control the industrial robot easily for the front-line operators.

In our research, hardware structure of "PC + motion controller" model is chosen, and Visual C++ development tool is used for software design, which develops a complier to edit and compile G-code. In addition, the message transmits between upper computer and ARM-based lower controller, through RS232 communication port. The operator does not need to spend a lot of time on learning professional robot programming control technology, but to input a series of simple G-code to achieve the specified movement of the robot. It obviously and effectually simplifies the workload of the operators, and it is easily applied in industry. This paper mainly includes two parts: the design of a G-code complier is introduced; using serial port communication technology realizes sending and receiving commands to guide the movement of robot.

The Design of Compiler

The Definition of G-Code Instructions

In CNC programming, G, F, S, T, M instructions are widely used to describe the operation mode of CNC machine tools, on behalf of different processing category. For the CNC operators, the programming is simple and convenient. But G-code was not originally for industrial robots, and selected because it is widely accepted in the manufacturing industry. Therefore, a kind of G-code complier was designed and implemented in this paper which is applied to control the robot motion. The users can not only program the robot motion with G-code commands but also change

motion parameters set by serial communication, to realize the automatic control of the robot.

It is necessary to design and develop an independent G-code compiler which can be saved in PC hard disk as an executable file or a library file and can be called by the operation layer. The compiler tasks are to implement the G-code syntax checking, exchanging relative coordinate to absolute coordinate, metric system and inch system exchanging, coordinate calculation of the centre of a circle, G-code subroutine treatment, and changing the G-code program into command sequence which is an absolutely sequential execution before machining. G-code program with numerous G-codes is compiled to a sequence of numerous instructions saved in PC hard-disk. During machining, PC sequentially sends instructions in batches into cycle buffers in lower micro computer (MC) through a serial port; and MC sequentially gets them from cycle buffers. Through identification of the instructions, MC not only can conveniently know the meaning of the current G-code, but also can get the corresponding parameters from the PC and can call the corresponding interpolation control function and thus the robot motion is implemented. General function module of control system is shown as Fig.1.

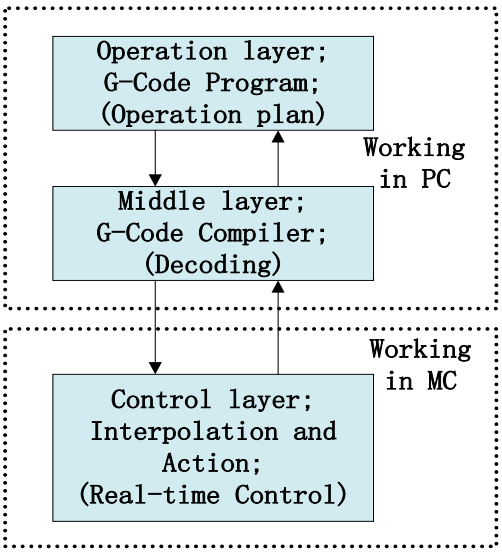

FIG. 1. GENERAL FUNCTION MODULE

As CNC machine programming instructions, G-code has a lot to adjust and change to fit for robot controlling. Imitating G-code compilation process for CNC, based on movement characteristic and the thought of software engineering, G-code compiler module is designed for four axis robot using VC ++ software platform. The compiler is with the functions of syntax checking and G-code conversion, as well as the G-code text saving or reading.

Syntax Checking Module of Compiler

The functions of the syntax checking module include scanning the new G-code file in sequence, ignoring the commentary lines, recording the error information when the error syntax line is caught, finding out valid lines and calling the line in compiling module. In addition, if any syntactic error exists then the error report file will be produced, the information about the error will be printed on the user interface. For example, it is forbidden to input character which has not been defined and coordinate values cannot exceed motion range of the robot.

In order to ensure the security of robot arms, it is necessary to set the soft limit in software. That is to say, if the coordinate value input by users exceeds the limit, error information will also occur on the user interface. And if the robot moves over the soft limit, the robot will stop. In this paper, maximum unfolded radius of SCARA Robot is 370 mm, the length of big arm (R1) is 220 mm, while the length of small arm (R2) is 150 mm, and the swing range of big arm is from -140° to 140°, the swing range of small arm is from -142° to 142°. Fig. 2 illustrates the simplified structure of Robot.

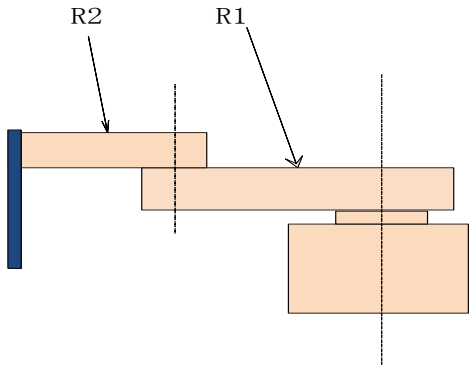

FIG. 2. THE SIMPLIFIED ROBOT STRUCTURE

To calculate the smallest radius (R) of the motion scope, triangle cosine theorem is applied to the function of checking coordinate value in this paper, as shown in equation (1).

$$a = \sqrt{\mathrm{b}^2 + c^2 - 2bc\cos A} \tag{1}$$

Where a, b and c represent R, R1 and R2 respectively.

Finally the coordinate values should be limited by equations (2).

$$\begin{cases} x^2 + y^2 > R^2 \\ x^2 + y^2 < (R_1 + R_2)^2 \\ (x - R_1 * \cos\alpha)^2 + (|y| - R_1 * \sin\alpha)^2 < {R_2}^2 \end{cases} \tag{2}$$

Where x, y and α are on behalf of the coordinate value

and limit angle between robot arm (R1) and X axis direction respectively. In order to improve the generality of the program, different movement range checking function should be designed according to the corresponding robot. That is to say, range checking function is not constant.

The compiler every time reads in a line of G code, then analyses it in order to check whether there is any illegal input, using global variables to identify mistakes.

The Design of Encoding Protocol

General Structure of Data Encoding

The key of lexical analysis is to explain word sequence of G-code program, and query and match according to body contents in the dictionary. The data encoding protocol is defined as following general structure shown in Fig.3.

The first part is the length of a line of G-code which describes the total unit number from command object code to the end of parameters which is called length of command field. The second part is command object code, which indentifies the kind of operation of Robot. MC receives the instruction, and then does the interpolation work, making corresponding control on robot movements. The third part is parameters, which indentifies coordinate value of target point and the speed of movement.

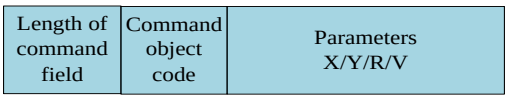

FIG.3. GENERAL STRUCTURE OF DATA ENCODING

Encoding Protocol for G-Code

A series of protocol is designed for encoding, to interpret the G-code program for a kind of data with appropriate format that can be received and recognized correctly by MC. Encoding is to put information the code contains, into corresponding units of data packet, such as length of command field, command object code, and the parameters. From command G00 to F, we arrange object code from 11000001 to 11001001, which is the only symbol to distinguish the commands. The length of command field is the number of keywords including command characters and parameter characters. For example, there is a line of G-code "G02 X100 Y250 R50", after decoding, the length of command field is "0xfc", the command object code is "0xc3", and the parameter value of X,Y,Z is "0x64", "0xfa" "0x32"respectively. It is known that string representation of the hex is easier for programmers to program, plan procedures and operate the serial port. On this account, we adopt this idea and formulate the protocol above. After decoding, all the G-codes that have been input by user can be converted into this kind of data packet, which is very convenient to communicate between PC and MC.

In the designed robot control system, we can encode all the G-code instructions input by user to the intermediate code which is very easy to transfer through serial port based on the protocol above. After receiving the data packet, MC responds the instructions correspondingly to make linear motion, or circular motion, and to change the speed or suspend. Table 1 shows all the robot G-code instructions.

TABLE 1 ROBOT G-CODE INSTRUCTIONS ENCODING

G-Code	Command Object Code	Function	Length Of Command Field
G00	11000001(0XC1)	Point to Point	11111011(0XFB)
G01	11000010(0XC2)	Line	11111011(0XFB)
G02	11000011(0XC3)	Clockwise arc	11111100(0XFC)
G04	11000100(0XC4)	Suspending	11111010(0XFA)
M00	11000101(0XC5)	Switching value 1	11111001(0XF9)
M01	11000110(0XC6)	Switching value 2	11111001(0XF9)
M02	11000111(0XC7)	Switching value 3	11111001(0XF9)
M03	11001000(0XC8)	Switching value 4	11111001(0XF9)
F	11001001(0XC9)	Speed of movement	11111010(0XFA)
G03	11001010(0XCA)	Counter-clockwise arc	11111100(0XFC)

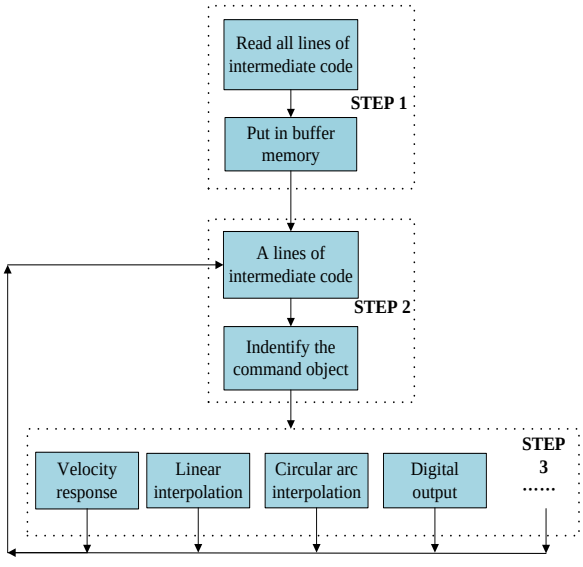

FIG. 4. FLOW CHART FOR MC'S WORK

The encoding data files stored in PC can be called as needed. When the user inputs G-code, after syntax checking and decoding, PC will send the compiled code to MC through serial port. Communication between PC and MC will be discussed in the following part of this paper. According to various G-code programs, the MC can make different response respectively. The general flow chart for MC's work is shown in Fig.4.

Design of Communication Protocol

Serial communication plays an important role in the modern industrial control systems. As a basic and flexible means of communication, it is widely used between PCs or between PC and PLC data exchange. In this paper, we choose MSComm control to realize the communication work between PC and MC because of its efficiency as well as convenience. After encoding, the data has been converted to intermediate file which is to be transmitted to the MC through serial port. We've designed a kind of protocol to implement the communication.

Communication Protocol

Start	Length of command field	Command object code	Parameter values	Stop

FIG. 5. FORMAT OF DATA FRAME

Interference and noise are often mixed with normal signal in the data communication procedure, in order to correctly identify the noise and effective data, two bytes protocol header are usually added to the front of the transmission data block. The data frame format is shown in Fig.5. After receiving "0x01" sent by PC, MC enters the mode of code download, at first the MC does a series of initialization, such as erasing the flash area, initializing location pointer; then, MC returns "0x01" to PC, in order to tell the PC to do the subsequent communication work; following, PC sends a data frame which selects "0x20"to be added as two bytes protocol header, if the MC receives data correctly, the PC sends next data frame continuously. If incorrect, it would order the PC to send the date once more. Finally, if all the data has been sent to MC successfully, MC returns "0x10" to remind PC to finish the transmission work. In this design, we can also change the robot hardware parameters on the PC interface, and then send the new parameters to the MC through serial port. MC distinguishes the two bytes protocol header to make the corresponding parameters calculated. So the versatility of software system is improved.

Software Design in the Communication System

The MSComm controller provides two ways to deal with communication problems: event-driven method and query method. In the process of communication, MC response time depends on the data size sent by PC, and the time of data storage as well as the calculation of inverse kinematics solution of the robot. Therefore event-driven method is selected to check whether there is valid data in buffer and to achieve responding function.

ActiveX control can be utilized to set up the connection with serial port and link with other communication apparatus, end demands, exchange data, guard and respond the events and defaults that happen in the series connection. Based on the communication protocol designed in the front, the next step is to achieve it in the program. After decoding work, the sending data has been converted into string form of hex, which is easily to be operated in the PC program. Then it is necessary to develop functions to change the variables of string kind into hex number. Finally, we send the G-code or Robot parameters configuration data to the MC through serial port on the basis of communication protocol.

Experimental Result

We take red trajectory shown in Fig.6 as an example to illustrate how to realize the movement of the robot by G-code program. Suppose that to control the end-effect or is desired to move from the origin point O (370, 0) to point A (270,200), green line OA is drawn, and then clockwise circular arc AB, counterclockwise arc BC, clockwise circular arc CD, and counterclockwise arc DE. After that, it moves back to point A, drawing along counterclockwise arc ED, clockwise circular arc DC, counterclockwise arc CB, and clockwise circular arc BA. The trajectories are four tangent full circles made in red. The experimental result is shown in Fig.9. And the G-code program should be formed as follow:

N01 G00 X370 Y0;

N02 G00 X270 Y200;

N03 G02 X270 Y100 R50;

N04 G03 X270 Y0 R50;

N05 G02 X270 Y-100 R50;

N06 G03 X270 Y-200 R50;

N07 G03 X270 Y-100 R50;

N08 G02 X270 Y0 R50;

N09 G03 X270 Y100 R50;

N10 G02 X270 Y200 R50;

Here we use the absolute coordinate system in the programming work; and the absolute origin is set at the joint of big arm and substrate. When user inputs G-code, after syntax checking and decoding, PC will send the compiled code to MC through serial port. Communication between PC and MC has also been discussed in this paper before. MC receives the compiled code data and extracts the data and motion information, and makes the corresponding action after inverse solution and interpolation, as well as sending feedback data through serial port to PC. Experiment result obtained from our designed SCARA robot is shown in Fig.7, and it can be seen the trajectory of robot is precise when user inputs correct G-code.

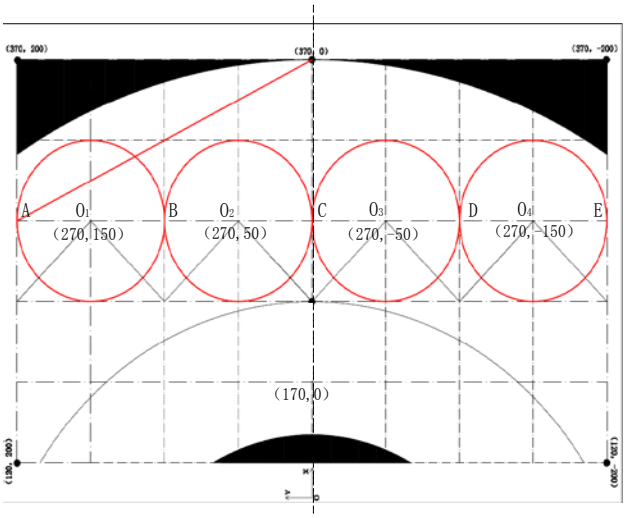

FIG.6. DESIRED TRAJECTORY OF ROBOT ACTUATOR

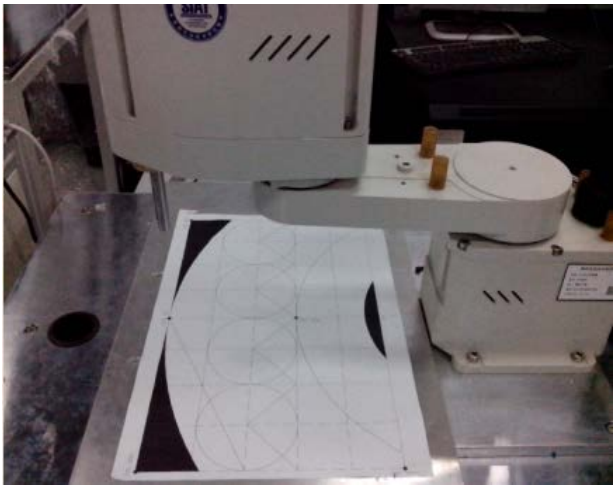

FIG.7. EXPERIMENTAL RESULT

Conclusion

In this research, a descriptive programming has been developed based on G-code encoding and transferring for the robot control system, by which the user can input simple G-code program to control the movements of robot. The user inputs G-code through PC interface, after syntax checking, the information contained in the code will be extracted and stored in a specific format, which is completed in PC. Then data stored and calculated by PC will be sent to MC through serial port for real-time controlling. The decoding and communication protocol formulated previously will be applied to ensure the applicability of the robot control system, and its easy operation will greatly reduce the work of user. The validity of the system has been confirmed by the experiment.

Acknowledgements

This work was financially supported by the Cooperation Project of Foshan and Institutes (2012HY100173), "Guangdong Introduced Leading Talents" project and the Strategic Cooperation Project of Guangdong Province and Chinese Academy of Sciences (2011A090100019). The authors would like to thank the support very much.

REFERENCES

Chen, Keming, Wang, Chunping. "The serial communication by using MSComm [A]." Journal of Pingxiang College, 2006, 6:40-42.

LUO, Yongsheng, JIANG, Tingbiao. "Information Extraction System Model Based on STEP-NC Program." Guilin University of Electronic Technology, Guilin, China.

Masood, Tariq, Khan, Iqbal, Akhtar, M. Jamil. "Using Extended G-Code Algorithms for Networked Industrial Robots." Fourth International Workshop on Robot Motion and Control, 2004(6):377-383.

Song, Tao. "Two Industrial Robots Coordination Operation Network Control Based On G-Code [J]." Automation Instrument, 2011, 32(8): 40-42.

Tang, Qiangping, Wu, Yu, Qin, Guorong. "A Middleware for Open CNC Architecture." Proceeding of the 2006 IEEE International Conference on Automation Science and Engineering, Shanghai, China, October 7-10, 2006: (558-561).

Wang, Yanfang, Mao, Wandui, Li, Jinying. "A Distributed

Rectifier Testing System Based on RS-485." IEEE Conference on Industrial Electronics and Applications, 2010(5): 779-781.

Zhang, Junjie, Wei, Wei. "The Application of Control Technology Based on Serial Port Communication." 2009 IITA International Conference on Control, Automation and Systems Engineering, Wuhan, Hubei, China, 2009: 472-475.